Phenomenology and Statistics of the Upper Slope sand Dunes in the Northeastern South China Sea

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Award Number: N0001413WX20392, N0001412WX20500

LONG-TERM GOALS

The long-term research goals are: (1) the characterization, understanding, and prediction of the statistics (mean, variance and coherence) of low-frequency acoustic signals and ambient noise in the littoral zone. The signal statistics are primarily influenced by the ocean variability and bottom properties. The noise statistics are influenced by atmospheric forcing and shipping in addition to the ocean and bottom variability; (2) the development and improvement of inverse techniques for measuring the dynamics and kinematics of meso- and finer-scale sound speed structure and ocean currents in coastal regions; (3) the understanding of three-dimensional sound propagation physics including horizontal refraction and azimuthal coupling and the quantification of the importance of these complex physics in the prediction of sound signals transmitted over highly variable littoral regions.

OBJECTIVES

The primary objectives of this three-year (FY12-14) research project are:

In collaboration with Taiwanese and US scientists, an ONR-sponsored, multi-year, interdisciplinary, international field program was launched to characterize the large sand dunes on the upper slope of the northeastern (NE) South China Sea (SCS), associated physical processes, and their impact on acoustic signal propagation and reverberation. Specifically, the joint field study has the following overall scientific goals:

- To characterize the time and space scales and the distribution of large submarine sand dunes on the upper slope.
- To study the impact of the sand dunes, and the combined impact of sand dunes and nonlinear internal waves, on sound propagation, in terms of phenomenology, including anisotropic propagation characteristics, and two-dimensional (2D) and three-dimensional (3D) focusing/defocusing scattering phenomena.
- To study the associated statistics (mean, variance and coherence) of sound signal propagation over the sand dunes and their dependence on range, frequency and orientation.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2014**	2. REPORT TYPE	3. DATES COVERED **00-00-2014 to 00-00-2014**

4. TITLE AND SUBTITLE **Phenomenology and Statistics of the Upper Slope sand Dunes in the Northeastern South China Sea**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Postgraduate School (NPS),Department of Oceanography,Monterey,CA,93943**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**9**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

- To examine the hypothesis that the internal tide and large trans-basin NLIWs are the generation mechanism of the dunes.
- To study how enhanced bottom roughness in the dune field affects transformation and energy dissipation of the NLIWs and tides as they shoal over the upper continental slope.

APPROACH

All fieldwork for this project was carried out in collaboration and coordination with our long-time Taiwan colleagues, utilizing their Research Vessels (RVs)—Ocean Researcher 1 (OR1), Ocean Researcher 2 (OR2), Ocean Researcher 3 (OR3) and their newest vessel, Ocean Researcher 5 (OR5). Pilot cruises were successfully carried out on the OR2 in 2012, and the OR2 and OR5 in 2013. The multibeam echosounder system (MBES) survey data collected in 2013 were used to design the main acoustic propagation experiment that was conducted in June 2014 aboard the OR1, OR3 and OR5. The cruises were scheduled to occur during a spring and a neap cycle of the tides, during which the internal waves had maximum and minimum amplitudes, respectively. The multi-ship operations were designed to allow the observation of the distribution and variation in spatial scales of the sand dunes, and examine the associated impacts on the sound fields over two cycles. It has been our hypothesis that the sound field and its statistics are primary controlled by the spatial scale and distribution of the sand dunes during the neap cycle, whereas they are controlled by a combination of the sand dunes and internal waves during the spring cycle.

WORK COMPLETED

The science objectives of the main field experiment of this sand dunes project were accomplished. A total of 23 days of ship time were provided by our Taiwanese colleagues: the first cruise occurred on the OR1 during May 31 – June 5, 2014; the second cruise was completed on the OR3 during June 8-12, 2014; and the third cruise was conducted on the OR5 from June 10-21, 2014. Two of the days of shiptime on the OR5 were funded via ONR Global.

OR1: Nine out of a total of ten moorings (acoustic and environmental) were deployed during the first two days on station, followed by sediment grabs and wave chasing with the "Lowered Package" (LP), which was a CTD carousel outfitted with CTD, transmissometer, flourometer, Lowered ADCP system, camera and lights, and two MAVS acoustic current meters, one of which had a newly-installed acoustic transmissometer. The LP was designed to measure the near-bed velocities and properties during NLIW passage as the NLIW propagated up the slope and onto the shelf, in order to look at sediment suspension by the NLIW's and the relation to sand dune formation/morphology. Several trans-basin waves were sampled, primarily in preparation for deployment during the OR5 cruise. The nearly full-water-column VLA (350 m) was deployed the day before the end of the cruise. Figure 1 shows the locations of the moorings, box cores and lowered source stations, and the track of the towed source.

OR3: A mid-frequency (MF) acoustic source was towed on two circles—one centered on the VLA in the middle of the sand dune field and the other centered on a SHRU that was located at the same location as the M mooring during the 2013 pilot cruise. Additional mid-frequency bottom-backscatter data were collected for geo-acoustic inversion of seabed acoustic properties.

OR5: Data collected/operations completed: (1) Completed additional MBES surveys of the sand dunes along the PO mooring track and of the area in the middle of the 'acoustic circle' in the sand dune field. (2) Dipped one of the sweeper sources off the fantail and transmitted signals to the VLA with and without a transbasin wave between source and VLA. (3) Deployed 3

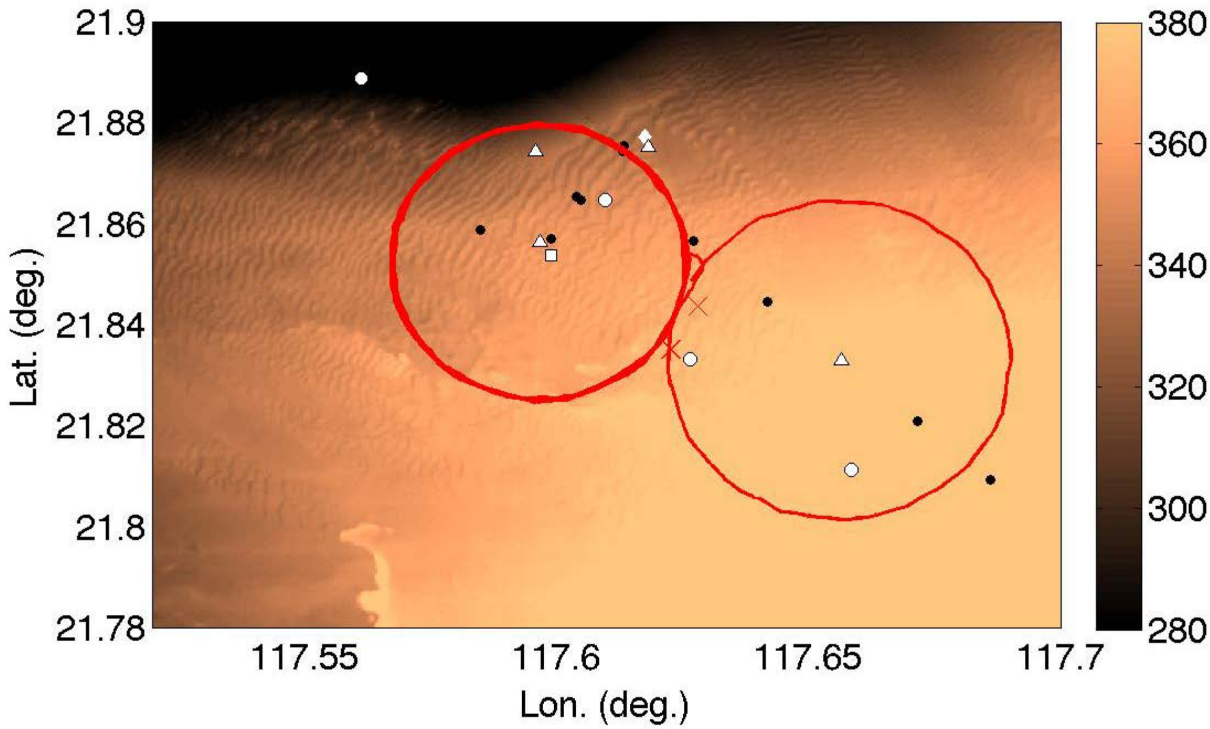

Fig. 1. Mooring laydown geometry during the main field experiment in June, 2014, superimposed on surveyed bathymetry. Moorings are shown in white (VLA = square, Source = diamond, SHRU = triangles, Environmental = circles), box core stations are indicated by black circles, lowered source stations are indicated by red 'X's, and towed source tracks are indicated by red lines.

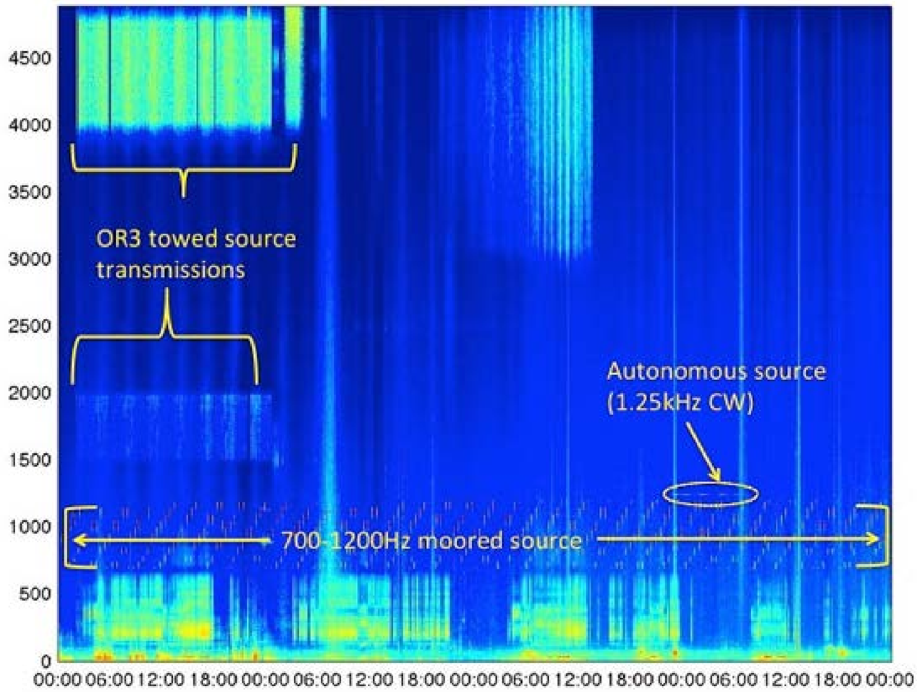

Fig. 2. Sprectrogram of representative acoustic signals received at the VLA.

EMATTs programmed to run along specific track lines IVO the acoustic circle. (4) Captured 6 transbasin wave events with the 'Lowered Package' (instruments on the CTD carousel). (5) During some crew downtime between mooring recoveries, additional MBES surveys were conducted and some sand dunes were found in some other locations. It appears that a specific slope angle is conducive to sand dune formation. All ten moorings and instruments were recovered at the end of the cruise.

Detailed information regarding the mooring locations, instruments and transmitted signals are provided in a forth-coming NPS technical report.

The FY14 effort focused on the execution of the main field experiment as outlined above, the plans for which were the result of intensive logistical planning, instrument and mooring preparation, and acoustic modeling to ensure optimal mooring placement to meet the scientific objectives.

RESULTS

While the time-intensive task of processing the large amount of data from the main experiment is ongoing, the following are some representative results from the 2013 pilot cruise data.

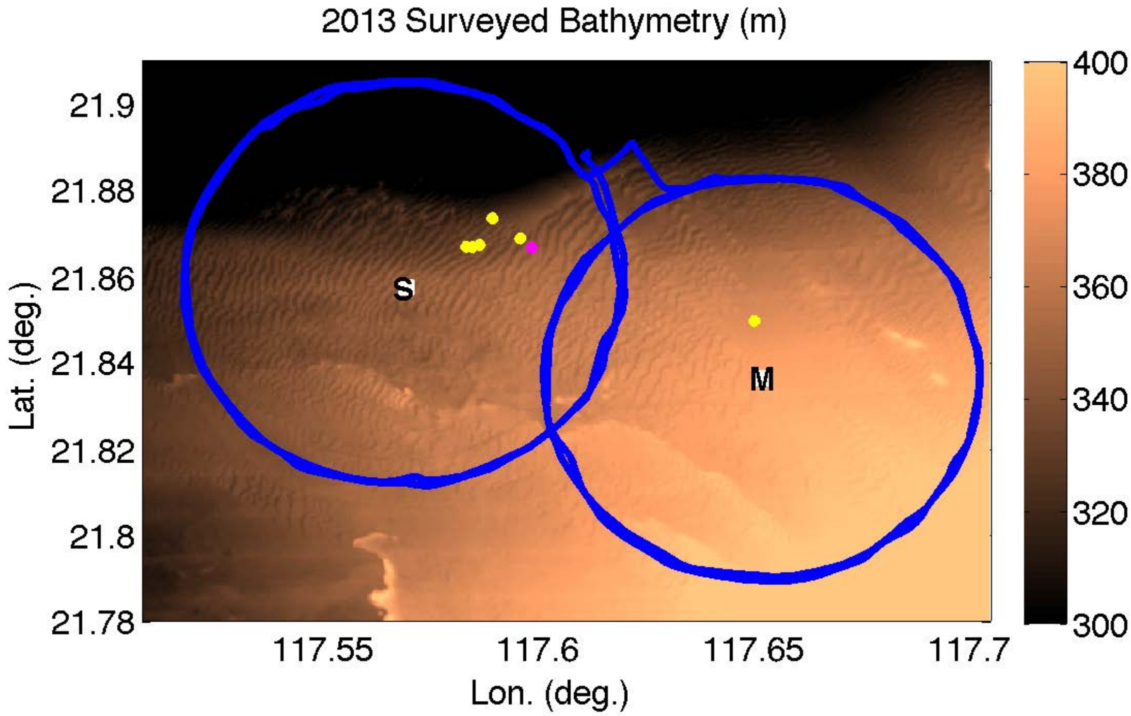

Fig. 3. LFM signals in the 900-2000 Hz and 4-6 kHz bands were transmitted by a towed source while transiting along the circular paths (blue), which are superimposed on thoroughly-analyzed MBES bathymetric survey data. M and S indicate the location of the two moorings, and yellow and magenta circles indicate the location of box cores.

The combination of MBES, coring and transmission data obtained from the two pilot experiments provided vital initial knowledge of (1) the spatial and temporal scales of the sand dunes from objective analysis, (2) the geoacoustic properties of the dunes based on forward modeling to matching the measured levels, and (3) the anisotropy and translational variability of the transmission loss at tactically relevant distances based on a signal energy analysis of the data. The acoustic signals were transmitted from a shallow source towed by the OR2 in a circle of 5-km radius centered on each of the moorings (Fig. 3). The signals alternated between low frequency (LF) and mid-frequency (MF) linear frequency modulated (LFM) and pseudo-random noise (m-sequence) signals in the 900-2000 Hz and 4000-6000 Hz bands. Figure 4 displays the measured signal energy level versus bearing angle for a deep receiver located at a depth of 320 m on the M mooring, showing notable anisotropic structures. Particularly, a depleted level for signals arriving from the SE between 120^{o} and 150^{o} relative to the levels in the other quadrants/angles. This is an expected and intuitive result owing to the fact that the source was towed at a shallow depth of 30 m. A shallow source would excite only high modes. The sand dunes in the NE and NW quadrants and the long seabed depression features in the SW quadrant would then cause a portion the energy initially contained in the high modes to scatter to the low modes, which could then propagate to the receiver more efficiently with relatively less loss to the bottom. The SE quadrant, however, had a smooth bathymetry that would cause little scattering, and thus the energy would largely remain in the high modes that would suffer appreciably more bottom losses before reaching the receiver.

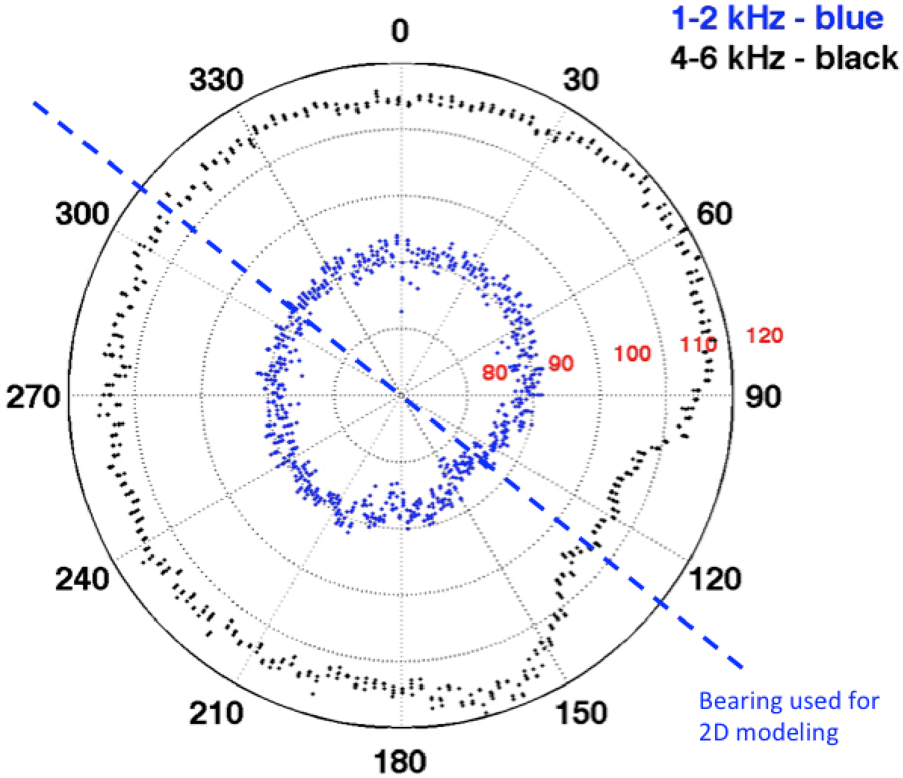

Fig. 4. Mid-frequency (blue = 1-2 kHz, black = 4-6 kHz) received signal energy level at the Acousonde hydrophone on Mooring M at the center of the 5-km radius circle around which the shallow acoustic source was towed, showing the anisotropy of the acoustic field at this particular location.

An initial estimation of the geoacoustic properties was accomplished using 2D forward acoustic modeling to match the measured signal transmission loss (TL) at two opposite bearings, 130o and 310o (marked by the blue dash line in Fig. 4). Starting with the multi-layered geoacoustic model developed by Lin et al. (2004) for the ASIAEX site west of our current experimental area, the compressional sound speed, attenuation rate and density for the top sediment layer were first adjusted, iteratively, to provide a best match to our measured TL at the higher frequency band (i.e., 4-6 kHz). The resultant best estimates for those three geoacoustic parameters are 1750 m/s, 0.15 dB per wavelength and 2,000 kg/m3, respectively, indicative of a very different kind of sediment: silty sand for the ASIAEX site versus a faster and more rigid sediment for our site that is composed of coarse sand with shells, consistently obtained by our box cores. Curiously, the values obtained here for the top sediment layer in the sand dune field are similar to those obtained by Holland (2002) for the shelly sand layers in the North Elba and Malta Plateau region in the Mediterranean.

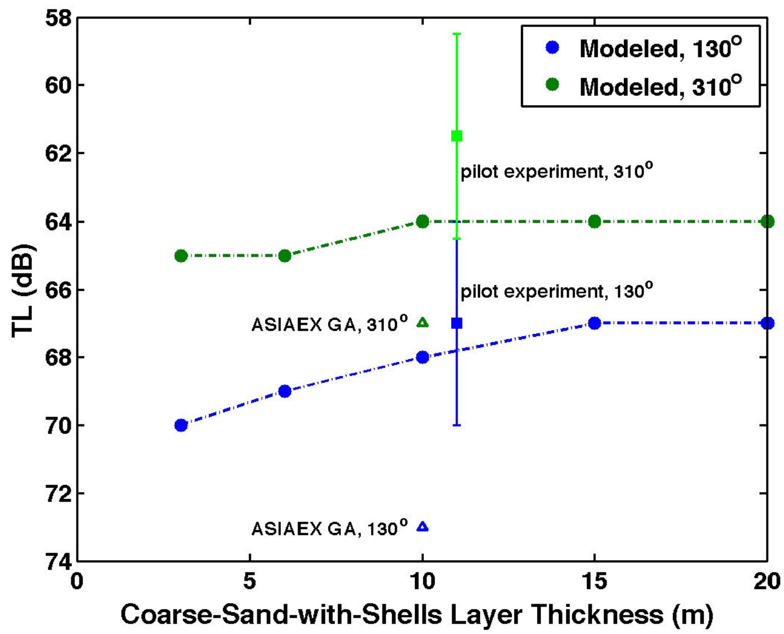

Fig. 5. Geo-acoustic forward modeling results: TL vs. layer thickness, with measured TL and associated standard deviations (squares with vertical bars) and modeled TL (circles).

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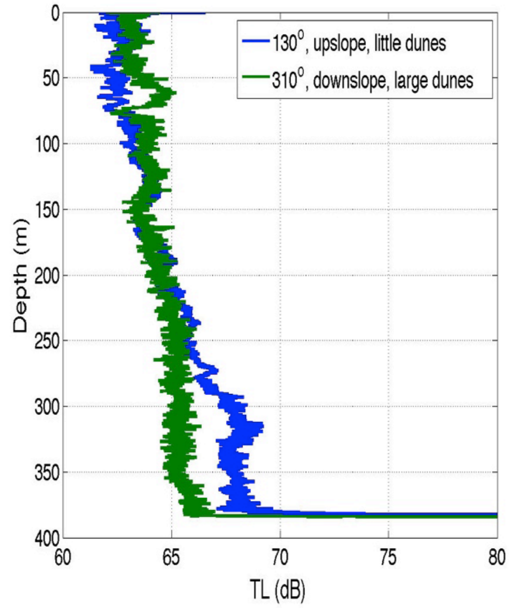
The modeled vertical distribution of TL at 5 kHz and 1.75 kHz, based on our initial geoacoustic model consisting of a 10-m layer of coarse sand with shells, are displayed in Fig. 6 to allow for a contrast and affirmation of how the acoustic energy is vertically redistributed by the large sand dunes (along 310o) for the case of a shallow sound source. This phenomenon was explained above in an earlier paragraph.



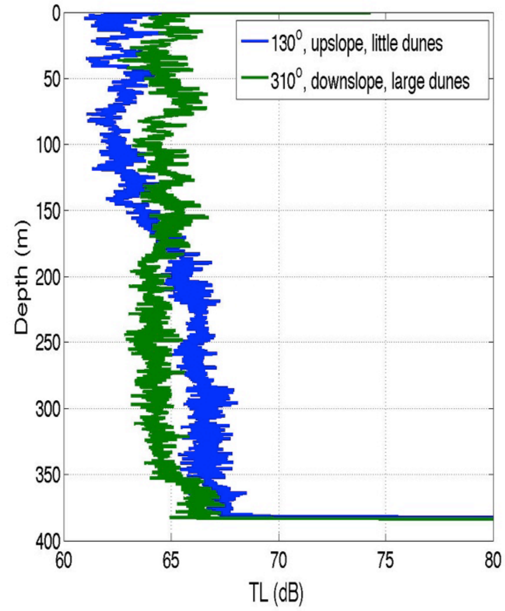


Fig. 6. Modeled vertical distribution of TL at 5.0 kHz (left) and 1.75 kHz (right).

Several presentations, technical reports and papers have been given/prepared/published within the context of this project (see references).

IMPACT/APPLICATIONS

This study will contribute to the foundational scientific knowledge required to (a) improve naval sonar system performance, based upon an understanding of the phenomenology and statistics of acoustic propagation in an environment having both sand dunes and ISW's. The dunes' location on the continental slope has profound implications on both active (i.e. increased reverberation from the continental slope for a surface ship operating in deeper water) and passive sonar (i.e. up/downslope propagation anomalies, angular dependencies, 3D effects, combined effects of the sand dunes and ISW's).

RELATED PROJECTS

This integrated acoustics, oceanography and geology experiment should extend the findings and data from SWARM, Shelfbreak PRIMER, ASIAEX, SW06 and NLIWI, thus improving our knowledge of the physics, variability, geographical dependence and predictability of sound propagation in a shelf-slope environment.

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